Canadian Space Agency | Agence spatiale canadienne

January 4, 1995

Office of the Secretary
Federal Communications Commission
Washington, DC 20554

Reference: FCC 94-272 In the Matter of Allocation of Spectrum Below 5 GHz Transferred from Federal Government Use.
ET Docket No. 94-32

Dear Sirs,

The American Institute of Aeronautics and Astronautics (AIAA) is the world's largest international aerospace professional organization. As such its concerns include, among other things, practical applications of space. One potential application of interest is that of providing solar power to earth by means of wireless power transmission.

The AIAA recently held a major workshop on International Space Cooperation, attended by senior experts from many countries. It was my privilege to serve as AIAA Co-chair of the *Solar Power to Earth* Working Group of this Workshop. This Working group addressed specifically the matter of proposed frequency reallocations within the ISM band and documented a finding and a recommendation as follows:

> Finding: "The frequency range in the microwave spectrum allocated to industrial, scientific, and medical use, known as the ISM Band (2400 to 2500 MHz), is in jeopardy from proposed incursions which could make it unavailable for crucial research and test programs".
>
> Recommendation: "Maintain presently assigned frequencies for power transmission experiments.
>
> An accompanying commentary to the recommendation was as follows: The Industrial, Scientific and Medical Band (frequency allocation) is essential for practical experimental progress in the transmission aspects of space power importation. Governments and industry in all interested countries should take appropriate steps to maintain this frequency assignment for its currently established functions.

The draft report of the *Solar Power to Earth* Working Group is appended to this letter.

The position of the Working Group stems from substantial world-wide interest in this potential application of space as a clean energy option for meeting pressing world needs. Various governments, industries and academic organizations are actively pursuing demonstrations and studies that will lead eventually to implementation of this new power source. Reallocation of key experimental frequencies would have a chilling effect on this work and delay and render more difficult the development of this important application of space.

We urge that the ISM band be preserved as presently assigned.

Sincerely,

R. Bryan Erb

R. Bryan Erb, D.Sc.
AIAA Co-chair, *Solar Power to Earth* Working Group

Canada

International Space Cooperation for Solar Power to Earth

Synopsis

Providing clean and economical energy is one of the most pressing challenges facing global society. The unlimited solar energy available in space suggests a solution to this most basic need of civilization. Capturing this energy in space and importing it to earth to meet human needs offers a space-technology-enabled solution to a pressing global problem which should be pursued along with other options for a sustainable energy future. The global scale and the technical, economic, and environmental challenges of implementing space solar power systems require international cooperation.

Significant demonstration and study work is presently being pursued on an international basis. Regardless of when large-scale implementation might take place, there are important additional activities that can and should be undertaken in the near term to enable more ambitious future endeavors and advance this use of space. The members of the *Solar Power to Earth Working Group* are resolved to plan and pursue action on this near term work in conjunction with the AIAA and other professional and advocacy organizations.

Introduction

This report summarizes the findings and recommendations of the *Solar Power to Earth Working Group* developed during the AIAA Workshop on International Space Cooperation[1]. The report also provides background material for those not familiar with this field, specifically: a brief elaboration of the energy/environmental problems, a short treatment of the basic technological approach to power importation, a summary of recent work and work in progress, and a list of key references.

The concept of importing power from space was first proposed many years ago and substantial work, both theoretical and experimental, has been done. The most extensive study was conducted by the U.S. Department of Energy and NASA in 1977-1980 to examine the feasibility of what was called the Solar Power Satellite. The conclusion of this study was that the approach was technically feasible and such satellites were projected to be economical under certain conditions. The National Research Council of the U.S. National Academy of Sciences did an assessment of this study and concluded that the assumptions were too optimistic, especially in the area of photovoltaic cell performance and probable launch costs. This assessment recommended that further relevant research be tracked and the situation be assessed from time to time, but that implementation not be pursued at that time.

Much has changed for the better in the intervening decade and a half, except for launch costs. Significant work has been done outside the U.S.A. Yet the situation of the early 1980s is still assumed by many to be the current reality. Such assumptions have largely prevented any U.S. governmental involvement since 1980 and this in itself is a major barrier to international cooperation. International acceptance of the viability of space power importation is spotty. Other barriers are:

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1 The Working Group wishes to thank other individuals who acted as consultants. The Planning Subcommittee included: Dr. Peter Glaser, Arthur D. Little Co., Ray Leonard, Los Alamos National Laboratory, Dr. Gay Canough, University of New York and ETM Inc., Gregg Maryniak, ISU, Dr. Wendell Mendell, NASA, and Dr. Bryan Erb, Canadian Space Agency. Aditionally, a Preparatory Session was held before the Workshop and, in addition to most of the members of the Planning Subcommittee, the following participated: Jerry Grey, AIAA, Harry Finger, Consultant, Ralph Nansen and Claude McIntire, Solar Space Industries and Fred Koomanoff, U.S. Department of Energy.

- Absence of a prominent space solar power agenda within any major international organization (although it is among the interests of many existing organizations)
- Lack of knowledge of past international work because the information is not easily accessible
- Perception of high risk, again due to lack of information on critical technical issues
- Lack of any substantial funding for demonstrations and development
- "Chicken-Egg" nature of Transportation Cost vs. Space Solar Power to Earth

Summary of Findings:

The *Solar Power to Earth Working Group* assessed the status and context of energy needs and the potential of a space-based solution to arrive at the following findings:

1. Providing clean and economical energy for the Earth's present and growing population is an environmental and economic imperative. There are, in addition, strong moral and political reasons for doing so. The dominant energy sources currently in use, fossil fuels, are not clean and will become increasingly costly as finite supplies are consumed. Furthermore, hydro power resources are nearing full exploitation considering the environmental constraints and fission nuclear power faces large environmental and political limits to further development. Fusion power remains a distant possibility.

2. Solar power from space can provide part of the solution to the global need for baseload[2] energy.

3. Energy is a market which dwarfs most other areas of economic activity. Global electricity production alone is presently a Trillion Dollar industry.

4. The world's space industry will continue to stagnate unless space is used to provide an economical solution to a significant global need. Market pull, rather than technology push, is absolutely necessary.

5. International activities in space solar power to earth, including ground and space demonstrations in the key area of wireless power transmission technology, are growing, with strong interest in France and Russia and a vigorous program in Japan. Bilateral international cooperation has played an important role in this area.

6. The lack of a U.S. government program is a significant impediment to international cooperation in this area. Countries have attempted to approach the U.S. to invite participation and have been rebuffed due to the lack of a defined responsibility within the government.

7. International cooperation is an effective and efficient means to accelerate progress in space solar power to earth. The development of ground test facilities for cooperative experimental and development activities is important and existing or prospective space facilities, such as Mir and the International Space Station should be considered as potentiual test beds...

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2 Energy available on a continuous basis. Other renewables, such as terrestrial and wind, can be very useful up to some portion of the total demand, but require costly storage to compete with fossil, nuclear and hydro as sources of baseload power.

8. Excellent technical progress has been made in power transmission, energy conversion, robotic construction and other relevant technologies since the Solar Power Satellite Studies of the 1970s and 1980s. However, space transportation costs remain high presenting a "Chicken and Egg" problem which must be solved before space solar power systems can be implemented.

9. A program of demonstrations and pilot operations is the best way to advance understanding and acceptance. This is particularly true in the area of the safety of wireless power transmission. Even though literally hundreds of studies uniformly find no biological show stoppers, the *Solar Power to Earth Working Group* believes that studies alone will be insufficient to convince the public that space solar power systems are both technically feasible and environmentally safe.

10. The frequency range in the microwave spectrum allocated to industrial, scientific, and medical use, known as the ISM Band (2400 to 2500 MHz), is in jeopardy from proposed incursions which could make it unavailable for crucial research and test programs.

11. Technical and Professional Societies and other advocacy groups are key to creating public and private sector interest in space solar power, to validating its credibility, and to educating industry, the public, and government decision makers. At present, activity in this area is spread thinly among many organizations with no one entity providing the necessary focus.

Summary of Recommendations

The forgoing findings lead to a number of recommendations organized in three categories: general, government and industry, and professional societies. These are as follows:

I General

Promote recognition that solar power from space for use on earth is an application which could help solve a pressing human need and, at the same time, provide a market for a vastly larger and more economical space transportation capability.

The capability for accessing space which would result from meeting the very substantial transportation needs of space solar power systems would, in turn, enable or strengthen other exciting applications of space and sustain a more robust exploration activity. This is ultimately a venue for commercial development; however,, at the current state of technology, strong government support, on an international basis, is important.

II Government and Industry

1. Establish a Department of Energy/NASA Program for space solar power to earth.

This recommendation is uniquely a U.S. matter. The existence of a Department of Energy/NASA activity, beginning simply with responsible points of contact in each agency, would create an appropriate focus for international cooperation. The two agencies could, jointly and with only a modest level of effort, follow, understand and document international efforts and be the clearing house and information source on the state of technical, environmental and socio-political aspects of power importation to Earth[3].

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3 The NRC Assessment recommended that relevant research be tracked on a continuing basis by these agencies.

Once the Department of Energy/NASA activity was stable, it could provide liaison with other U.S. government departments (e.g. Commerce and EPA) to form and lead a Government-Industry Council on Space Solar Power to Earth. This Council could oversee the development of a National Space Power Plan which, in turn, could provide the basis for meaningful international collaboration.

2. Develop international demonstration programs and facilities.

International experimental and development facilities such as Space Station, ground-based test ranges, and bilateral and multilateral experimental and developmental programs could be used to accelerate progress and could build upon existing efforts and relationships. A major goal of this recommendation is to reduce economic and political risk though step-by-step activities each of which should be designed to provide significant technical results and to increase public confidence. Cooperation between government and industry is required.

3. Maintain presently assigned frequencies for power transmission experiments.

The Industrial, Scientific and Medical Band (frequency allocation) is essential for practical experimental progress in the transmission aspects of space power importation. Governments and industry in all interested countries should take appropriate steps to maintain this frequency assignment for its currently established functions.

III Professional Societies

1. Publish a position paper on Space Solar Power to Earth.

Such a position paper would document technical status and progress and foster international discussion. In the interim, until some of the following recommendations have been implemented, such a position paper could be developed by the AIAA's International Activities Committee and the *Solar Power to Earth Working Group* of this AIAA Workshop.

2. Convene a workshop on Transportation Requirements for Space Solar Power Systems.

The critical and interdependent nature of space transportation and space power requirements merits a near-term, detailed, examination of these requirements. Again, the AIAA could lead this effort, perhaps organizing it as part of an appropriate conference.

3. Establish a Technical Committee of the AIAA to address space power.

Such a committee would be chartered to monitor and advance the technical aspects of the field, and to foster international cooperation. It would also provide a nucleus for special efforts such as the position paper and the conference recommended in items 1 and 2 above.

4. Establish an Internet-based network on space power.

The first steps have been taken at this AIAA Workshop, with the general acceptance of the Space Power Network (SP-Net) proposal from Japan. Implementation of an Internet mechanism will permit increased international discussion and interaction.

5. Appropriate follow-on activity to this AIAA Workshop should be promoted with national and international societies.

The AIAA should take a lead role and engage the involvement of other professional and advocacy groups in promoting appropriate follow-on activities on space power among national

and international societies. The societies engaged should include those serving the energy and environmental communities in addition to those involved with the space community.

6. Create an International Council on Space Solar Power to Earth.

A goal of inter-society activity should be the creation of an International Council on Space Solar Power to Earth to foster coordination and cooperation in international efforts. In addition to the AIAA, the Council should have representation from the International Astronautical Federation, the Institute of Electrical and Electronic Engineers, the American Society of Civil Engineers, the Société des Electriciens et des Electroniciens, Sunsat Energy Council, National Space Society as well as other societies and organizations representing energy, environmental, financial, and development interests. Key roles for this Council would include international outreach and marketing efforts and the facilitation of international cooperative projects. The Council would actively foster the participation of Developing Countries, aid in industry/government/academia collaboration on an international basis, and continue regular Wireless Power Transmission Conferences.

There are excellent precedents in the astronomy and nuclear physics communities for international professional collaboration of this type. Furthermore, in alliance with governments and industry, the Council could assist in maintaining key experimental frequency assignments. In additional to the International Council, it might be productive to promote local and regional groups to support the international efforts.

Background Information

I The Energy/Environment Challenge

The global environment is in decline and large sectors of the human population face bleak prospects[4]. Lack of ample clean energy, particularly in the rural populations of the Developing Countries, is a fundamental impediment to development and hence to education, stabilization of population, world stability and global prosperity.

The continued use of fossil fuels is a major cause of the environmental decline and we are probably committed already to significant climate changes as a result. Other environmental degradation is due to an unsustainable use of fuel wood. Importing electricity from space addresses this problem by providing energy without adding to emmissions or waste.

II The Technological Approach

The basic concept is to capture solar energy in space on large satellite platforms, convert it to radio frequency energy and transmit it to receiving antennas that convert the radio frequency energy back into electrical energy which is then either fed into the power grid or used to produce hydrogen and synthetic fuels.

Various means of energy conversion have been suggested, but the current emphasis is on photovoltaics. Alternative transmission approaches with lasers have been suggested; however, radio frequencies appear most useful in the near term because the technology is proven and conversion efficiencies are high.

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4 This outlook was described at the 15th World Energy Congress by R.K. Pachauri of India as follows: "A large part of the human race is today gripped by widespread poverty, which [situation] can only be improved through an absolute minimum level of energy use as an input to a range of activities that provide the most basic of services for secure and stable human existence. These services include at least a clean water supply, refrigeration for the village health center, lighting at night and, perhaps, a community TV."

Studies have indicated that non-terrestrial resources (from lunar or asteroidal sources) may eventually be the most economical way of supporting a mature, space-based manufacturing operation for solar power satellites and other space-based industries.

Wireless power transmission from point-to-point on the ground (across difficult terrain) or from the ground to high altitude long-endurance aircraft (for communications or other purposes) may provide logical stepping stones to importation of solar power from satellites.

III Recent Work and Work in Progress

The last decade has seen substantial progress with rocket experiments, microwave-powered aircraft flights, major conferences and serious research presented at international symposia. It has also seen support from entities such as the U.S. National Commission on Space (Paine Commission) and UNESCO via their World Solar Summit. Ground power transmission tests have been conducted recently in Japan and a pilot project in Reunion Island is being considered jointly by France and Japan. High-altitude aircraft applications are being pursued by U.S., French, and Canadian interests.

Academic interest is also strong. In 1992 the International Space University chose Space Solar Power for Earth as one of their summer session design projects and followed up by creating an International Space Power Program. Japanese researchers at Kobe University and in the Institute for Space and Astronautical Sciences are carrying out leading-edge projects with a strong hardware emphasis. The Center for Space Power at Texas A&M University organized Wireless Power Transmission (WPT) 93, and developed efficient rectennas for use at frequencies higher than 2.45 GHz and a slotted wave guide phased array transmitting antenna for operation at 2.45 GHz. Students at the University of Alaska, Fairbanks, have designed spacecraft to receive power from the earth (for propagation experiments) and are participating with Japan in a microwave helicopter project.

In October 1995, Japan will host the next major conference relevant to Space Solar Power to Earth, i.e. WPT 95. This conference will also be the venue of further international demonstrations including that of the microwave helicopter.

It is important to recognize what has changed between 1980 and the present. A summary of this is presented in the table below.

Then (1980)	Now (1994)
Photovoltaics - fledgling industry Expensive, over $100 per watt Low efficiency Small production	Photovoltaics - maturing industry Pricing dropping toward $1 per watt Improved efficiencies Single crystal Poly crystal Thin film Robust, expanding capacity
Transportation Pre-shuttle	Transportation Still costly, but more options Reusability demonstrated
Wireless Power Transmission Goldstone ground test ISM band initial steps taken	Wireless Power Transmission In-space transmission experiments More Biological studies, no show stoppers Increased fear of Electro-Magnetic Fields ISM band in jeopardy 5.8 & 35 GHz technology Laser development
Construction of SPS Big fixtures / Space Factories	Construction of SPS Robotic assembly (automation industry) No big fixture, build upon itself.
Stimulus Energy supply/cost crises (U.S.A. focus) Concern for strategic supply	Stimulus Environmental degredation Rapid growth in economies of the Developing Countries Supply that is sustainable
Ground Segment 10-13 km for 5 GW	Ground Segment 3 km diameter for 1 GW Thin film - lightweight arrays
Trends Technical Risk declining due to maturity of: PV, WPT, Transport, and Robotics Construction safety up due to construction robotics System "natural growth" Aircraft -> WPT -> SPS --> Moon	

IV Key References.

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